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Mapping and assessment of karst landscape aesthetic value from a world heritage perspective: a case study of the Huangguoshu Scenic area

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Abstract

Aesthetic value is an essential component of outstanding universal value (OUV) for natural world heritage (NWH) site. However, comparisons of aesthetic value lack a set of effective evaluation systems. In the identification of aesthetic value, there is subjectivity and difficulty in quantifying the methodology suggested by the IUCN in the operation manual, and it is difficult to compare in different NWH sites. This study focused on establishing a universal system to map and assess the aesthetic value of karst NWH sites. The research focused on three dimensions: naturalness, diversity, and uniqueness. The final combination of the three is achieved by geographic information system (GIS)-based spatial map overlay analysis with multisource data. To verify the rationality of the model, the aesthetic value of a case study in the Huangguoshu Scenic Area in China at the WH nominated site was evaluated. The results revealed that the areas with low, relatively low, medium, relatively high, and high values accounted for 12.2%, 20.2%, 32.4%, 21.4% and 13.8%, respectively. The distribution of aesthetic value is basically consistent with the boundary division of the NWH site, and high scores are mostly distributed in areas with high protection levels. Moreover, the impacts of naturalness, uniqueness and diversity on aesthetic value in the research area are in decreasing order. Furthermore, the research analyses the aesthetic characteristics and causes at different levels. The research area combines the quintessential nature of karst, hills and water, caves, fenglin and historic villages; it unifies sturdiness, peculiarity, precipitousness, and peace. Among the 7 nominated NWH sites, the Huangguoshu Waterfall has the highest aesthetic value, while those of Tiantaishan Ancient Temple and Getuhe are relatively low. The rationality of the evaluation system for extracting areas with high aesthetic value was demonstrated. This study compensates for the limitation of the inability of existing studies to quantify the aesthetic value. This approach fills a previous gap in the research on the aesthetic value of WH and can provide a useful reference for better protection and management decisions.

Keywords World heritage site, Aesthetic value, Mapping and assessment, GIS-based spatial overlay analysis, Karst landscape

Introduction

World heritage (WH) sites are priceless and irreplaceable assets attributed to every nation and humanity as a whole [1]. The Convention Concerning the Protection of the World Cultural and Natural Heritage (hereinafter referred to as “the Convention”) considers WH sites to have “outstanding universal value” (OUV), that is, cultural and/or natural significance exceptional enough

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to transcend national boundaries and possess collective importance for present and future generations. Therefore, WH sites deserve special protection [1]. The purpose of the Convention is to identify, protect, preserve, present, and transmit cultural and natural heritage with OUV to future generations. WH protection is founded on the existential value of natural and cultural heritage and considers the elements, composition, interpretation, and maintenance of this value [2]; furthermore, the identification of OUV and protection based on these factors has reached a consensus [3, 4]. The World Heritage Committee (WHC) has developed ten criteria for determining WH sites; a site has an OUV if one or more of the ten criteria are met [5]. Criteria vii to x refer to natural heritage. Criterion vii is applicable to a site containing “superlative natural phenomena or areas of exceptional natural beauty and esthetic importance” [5]. In the WH research realm, “natural beauty” refers to the aesthetic value of natural heritage and can describe natural phenomena or regional aesthetic quality. Currently, of the 227 NWH sites and 39 mixed WH sites found worldwide, 148 (65.20%) meet criterion vii. There are 5 karst-related WH sites in China, namely Huanglong, Jiuzhaigou Valley, Wulingyuan Scenic and Historic Interest Area, Three Parallel Rivers of Yunnan, and South China Karst.

The aesthetic landscape of Natural World Heritage (NWH) sites is an embodiment of the earth's processes and an important tourist attraction; these sites are particularly helpful for developing countries, where the tourism industry is encouraged to lift local people out of poverty and boost local financial revenues [6–8]. The aesthetic value of these sites is one of their greatest values. However, UNESCO's guidance on the application of criterion vii is limited and not as systematic or rigorous as that for other natural standards [9]. Compared to other natural resources, natural scenery is more difficult to evaluate in a scientific manner because it depends not only on the nature of the landscape and its profound cultural connotation but also largely on the subjective assessment of the viewer [10–12]. Notably, the content of criterion vii has undergone six highly controversial revisions due to the different types of regional environments and landscapes considered, complex issues that emerge at different levels of consideration, subjective and difficult-to-quantify evaluations and other problems that often arise during its application. As a result of these controversies, the scientific and objective application of criterion vii has been questioned [13, 14]. Therefore, exploring methods for evaluating aesthetic value and strengthening the guidance of the evaluation process remain important to the field of heritage value research.

To address this key issue, scholars have explored and employed a variety of aesthetic evaluation methods.

Most scholars [15, 16] have used the global framework approach recommended by UNESCO to evaluate the aesthetic value of natural scenery. This method requires comparisons and analyses of qualitative descriptions of similar heritage sites with natural beauty attributes to indicate their aesthetic value and importance. Other scholars have evaluated landscape aesthetics based on interviews, questionnaires, experiments, participation in mapping and other methods; these approaches allow them to study people's views and preferences for WH sites [17–20]. The typical evaluation object is a single or a small-scale landscape. These studies provide valuable insights into the relationship between the physical features of landscapes and people's subjective aesthetic values but rarely map and assess the results with measurable indicators. Moreover, the resource manual for preparing WH nominations suggests that “measurable scenic indicators should be used wherever possible” [21].

To summarize, scientific discourse is slowly moving toward establishing objective landscape aesthetic indicators; this process is still ongoing. The selection of the method is closely related to the spatial scale and environmental features of the evaluation object. Due to the vast area and complex geographical features of NWH sites, relatively abstract and simplified indicators that can reflect the inherent attributes of the landscape are needed. A total of 26 karst areas worldwide have been included on the WH List under either criterion vii or in combination with other criteria, indicating that WH karst sites are high-quality landscapes that integrate natural and aesthetic values. Moreover, karst ecosystems uniquely integrate both surface and subterranean elements, weaving together a variety of biological and physical processes [22] that are characterized by barren soil and rich biodiversity. These landscapes have been sculpted over millennia by dissolution processes into distinctive features such as poljes, dolines, sinkholes, towers, caves, shafts, dry valleys, and underground rivers [23]. However, they remain highly sensitive to human activities and ecosystems are fragile and easily disturbed, so they have received extensive attention [22–25]. How to abstract an indicator system with geographical data that considers the physical attributes of aesthetic and ecological functions to evaluate the aesthetic value of karst NWH sites remains an open question. The answers to this question can supplement the knowledge system of WH value research and provide a reference for similar types of NWH sites.

The aim of this study is to map and assess the aesthetic value of karst WH. This paper chooses the Huangguoshu Scenic Area among the nominated NWH sites of China as a case study and uses multisource data to focus on the three dimensions of naturalness, diversity,

and uniqueness. These attributes are combined via geographic information system (GIS)-based spatial map overlay analysis. In addition, this study analyzes the different levels of aesthetic characteristics and causes. In this study, an indicator system was constructed that is generally applicable to the aesthetic evaluation of NWH sites and can serve as a basis for comparing the results of different countries for aesthetic value identification. This system can provide an effective reference for better protection and management decisions.

Materials and methods

Study areas

The Huangguoshu Scenic Area, a component of the Yunnan-Guizhou Plateau, is located in South China and has a nominated area of 114.24 km² and a buffer zone of 319.56 km² (Fig. 1). The scope of the WH site area mainly includes three parts (Fig. 1c), namely, the Tunpu Scenic Spot, Huangguoshu Scenic Spot and Getuhe Scenic Spot. All three regions are designated National Scenic Areas in China. Additionally, the Tunpu Scenic Spot has been listed as an important Agricultural Cultural Heritage site in China, the Huangguoshu Scenic Spot has been

classified as a National Geopark and listed on the IUCN Green List, and the Getuhe Scenic Spot has been designated as both a National Nature Reserve and a National Geopark.

The study area is characterized by a subtropical humid monsoon climate, featuring hot, rainy summers and mild, moist winters. It receives an average annual rainfall exceeding 1,250 mm and maintains an average temperature of 14 °C. This climate fosters pronounced seasonal variations and copious precipitation, which in turn supports the formation of numerous rivers and an extensive hydrological network. The predominant limestone soil underpin a lush vegetation cover, contributing to the area's exceptionally high biodiversity. Additionally, the region is home to diverse ethnic groups, each preserving distinct cultural identities and traditions. The mean altitude of the area is approximately 900 m, marked by prevalent limestone formations and significant karst activity. Karst landforms and landscapes, for instance, fengcong, fenglin, karst depressions and karst gorge caves, are common throughout the area. These formations offer outstanding examples of the response of Cenozoic landforms to neotectonic movement during Earth's evolution [26].

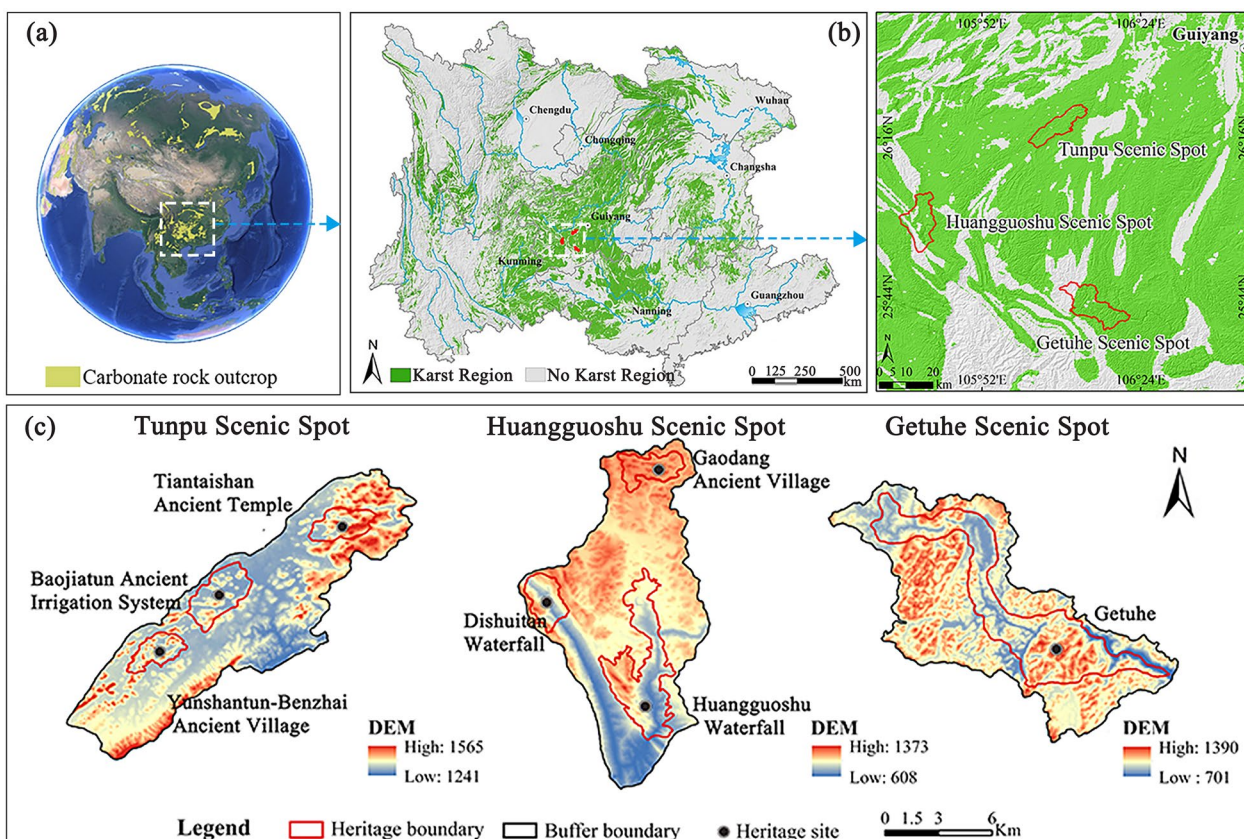


Fig. 1 Location of Huangguoshu Scenic Area (a. Karst outburst distribution in the northern hemisphere; b. Spatial distribution map of South China Karst; c. Digital Elevation Model (DEM) of Huangguoshu Scenic Area)

In 2019, the Huangguoshu Scenic Area was inscribed on the Nominated List of WH sites based on Criteria v: to be an outstanding example of a traditional human settlement, land use, or sea use that is representative of a culture (or cultures), or human interaction with the environment especially when it has become vulnerable under the impact of irreversible change. Criterion vii: contains superlative natural phenomena or areas of exceptional natural beauty and aesthetic importance. Criterion viii: outstanding examples representing major stages of Earth's history, including the record of life, significant ongoing geological processes in the development of landforms, or significant geomorphic or physiographic features.

Framework and approach

This study designed a framework to map and assess the aesthetic value of the Huangguoshu Scenic Area that based on the methodology proposed by Hermes et al. [27]. Aesthetic value is an overlay of landscape diversity, landscape naturalness, and landscape uniqueness indicators. To determine subindicators for evaluation, first, the related literature was reviewed, including aesthetic evaluations and landscape aesthetic quality/attractiveness evaluations for scenic parks in general [20, 31, 32] and for those at larger regional/national scales [25, 28, 29, 33]; moreover, relevant studies on landscape and environmental planning [34, 35] and environmental psychology [36, 37] were also reviewed for approach reference. Based on a comparison of aesthetic value evaluation systems from similar studies [27, 38] and accounting for the particularity of NWH sites, an evaluation system is developed.

Landscape naturalness

The indices selected in this dimension include perceived naturalness, disturbance degree of human activities and vegetation coverage. First, evaluations of the perception of naturalness are based on people's different aesthetic experiences of land cover types with different degrees of naturalness [29]. With reference to the research of Walz et al. [28] and the land use classification of the study

area, the perceived naturalness score based on land cover (Table 1). Secondly, the degree of human interference serves as a sub-indicator for landscape naturalness. This indicator is quantified by the intensity of human activity, considering factors such as night lighting, railways, roads, and constructed land cover. These elements are treated as measures of human activity intensity, which negatively impact naturalness. In this study, the data are integrated through overlay analysis to assess their combined effect. Finally, Gobster [39] proposed that the study of aesthetics should not focus on the scenic aesthetic, but instead should focus on the ecological environment. Vegetation coverage is an important and rare index reflecting the regional ecological environment [29]. Therefore, the normalized vegetation index (NDVI) is used to characterize the extent of vegetation coverage in this paper.

Landscape uniqueness

Three indices, namely, the rarity of landforms, slope aspect and uniqueness provoking indicators are used to form this dimension. Geomorphic type influences landscape perception and value formation and best represents landscape uniqueness at the regional scale. Referring to the research of Hou et al. [40] and Liu et al. [33], low-frequency (high score) and high-frequency (low score) topographical features are used for classification. According to the area shares and intergroup differences, seven levels of rareness was defined based on score thresholds of 5%, 3%, 1%, 0.5%, 0.2%, and 0.1% and assigned values of 1–6. Second, the slope direction strongly impacts the natural ecology of the mountain, as it determines the direction of runoff erosion and the water and thermal conditions of plant growth. The south-facing slope area has a good ecological environment and abundant landscape resources. Therefore, 5 grades were divided by the slopes according to the sunshine orientation: (1) north to northeast and northwest to north, (2) northeast to southeast, (3) plane, (4) southeast to southwest, and (5) southwest to northwest. This work is calculated by reclassifying DEM data. Finally, for the uniqueness provoking indicators, considering the OUV of the study area, the geomorphic landscape is taken as the basis of aesthetic value. Since

Table 1 Perceived naturalness score based on land cover types

Types	Score
Urban land; Rural residential area; Rural road; Highway land; Railway land; Other construction land	1
Bare rock stony land; Facility agricultural land; Water conservancy facilities building land	2
Orchards; Other gardens; Other woodlands; Other meadows	3
Artificial grassland; Tea gardens; Ditches; Ponds; Breeding pond	4
Reservoir surface; shrub; Bamboo forest land; Paddy field; Irrigated land; Dryland	5
Arborland; Inland beach; River surface; Natural grassland	6

data on “rare” or “unique” features are scarce, in this case, the geological heritage sites and scenic resources ranged according to the classification levels in China. The values were assigned for different levels via the kriging interpolation method.

Landscape diversity

In this dimension, three indices, namely, land cover diversity, topographic diversity and structural diversity, were selected. First, land cover diversity is measured using the Shannon diversity index (SHDI), which represents the relationship between the number and spatial proportion of regional land cover types [41, 42]; SHDI was measured based on the information entropy of the spatial distribution of land cover types. Second, topographic diversity is usually measured by topographic relief, which refers to the difference between the highest elevation and the lowest elevation in a specific area. Finally, based on the study of Sowińska [43], the patch edge density index is used to measure structural diversity, and the complexity of patch shape, patch density and diversity of natural landscape elements are analyzed.

Index weight coefficients

This paper’s aesthetic value calculation index weights are based on the methodology proposed by Hermes et al. [27]. First, the three dimensions of landscape naturalness, diversity and uniqueness are weighted equally. Second, for specific index factors including naturalness perception, disturbance degree of human activities and vegetation cover in the landscape naturalness measurement, the assigned weights are 0.66, 0.17 and 0.17, respectively. To measure landscape uniqueness, the rarity of terrain and landforms and the uniqueness and slope direction of landscape resources are equally weighted. Likewise, to measure landscape diversity, land cover diversity,

structural diversity and topographic diversity are equally weighted (Table 2).

Data sources and processing

Data sources

The land use data were obtained from Guizhou Karst Mountain Ecology National Laboratory for Environmental Sciences Cultivation Base. The year selected was 2022; the data for this year included 10 first-level classifications and 25 second-level classifications, with a spatial resolution of 30 m. The DEM data were obtained from NASA’s earth science website (<https://nasadaacs.eos.nasa.gov>), and the spatial resolution was 25 m. Heritage site boundary vector data were obtained from the WHC (<https://whc.unesco.org/en/soc>). The NDVI data was obtained from the National Tibetan Plateau Data Center (<http://data.tpdc.ac.cn>), and it is based on the Aqua/Terra-MODIS satellite sensor MOD13Q1 product and land use data. The night light data were obtained from the Luo-jia-1 satellite data center website (<http://59.175.109.173:8888/app/login.html>). The data on railways, roads, and land cover construction land types were obtained from the National Spatial Information on Roads and the Data Center for Resources and Environmental Sciences, Chinese Academy of Sciences (<https://www.resdc.cn/>), with a spatial resolution of 30 m.

The calculation process

The “moving windows” function in Fragstats 4.2 and ArcGIS 10.8 is used to quantify and assign each index, as shown in Fig. 2.

Step 1 Data with different spatial resolutions are resampled into 30 m × 30 m grids, the scores of each single index are calculated, and the results are normalized.

The normalization formula for the forward index is:

Table 2 Evaluation indicator system of natural aesthetic value in Huangguoshu Scenic Area

Aesthetic value dimensions	Weight	Indicator	Weight	Factors	Indicator attribute
Landscape naturalness	0.33	Perceived naturalness	0.66	Naturalness perception score	+
		Interference degree of human activity	0.17	Intensity of human activity	–
		Vegetation coverage	0.17	Normalized vegetation coverage (NDVI)	+
Landscape diversity	0.33	Land cover diversity	0.33	Shannon Diversity (SHDI)	+
		Structural diversity	0.33	Patch edge density (PD)	+
		Topographic diversity	0.33	Relief degree of land surface	+
Landscape uniqueness	0.33	Rareness of landform	0.33	Topographic and geomorphic classification score	+
		Slope aspect	0.33	Sunshine orientation	+
		Uniqueness provoking indicators	0.33	Geoheritage and scenic resources classification score	+

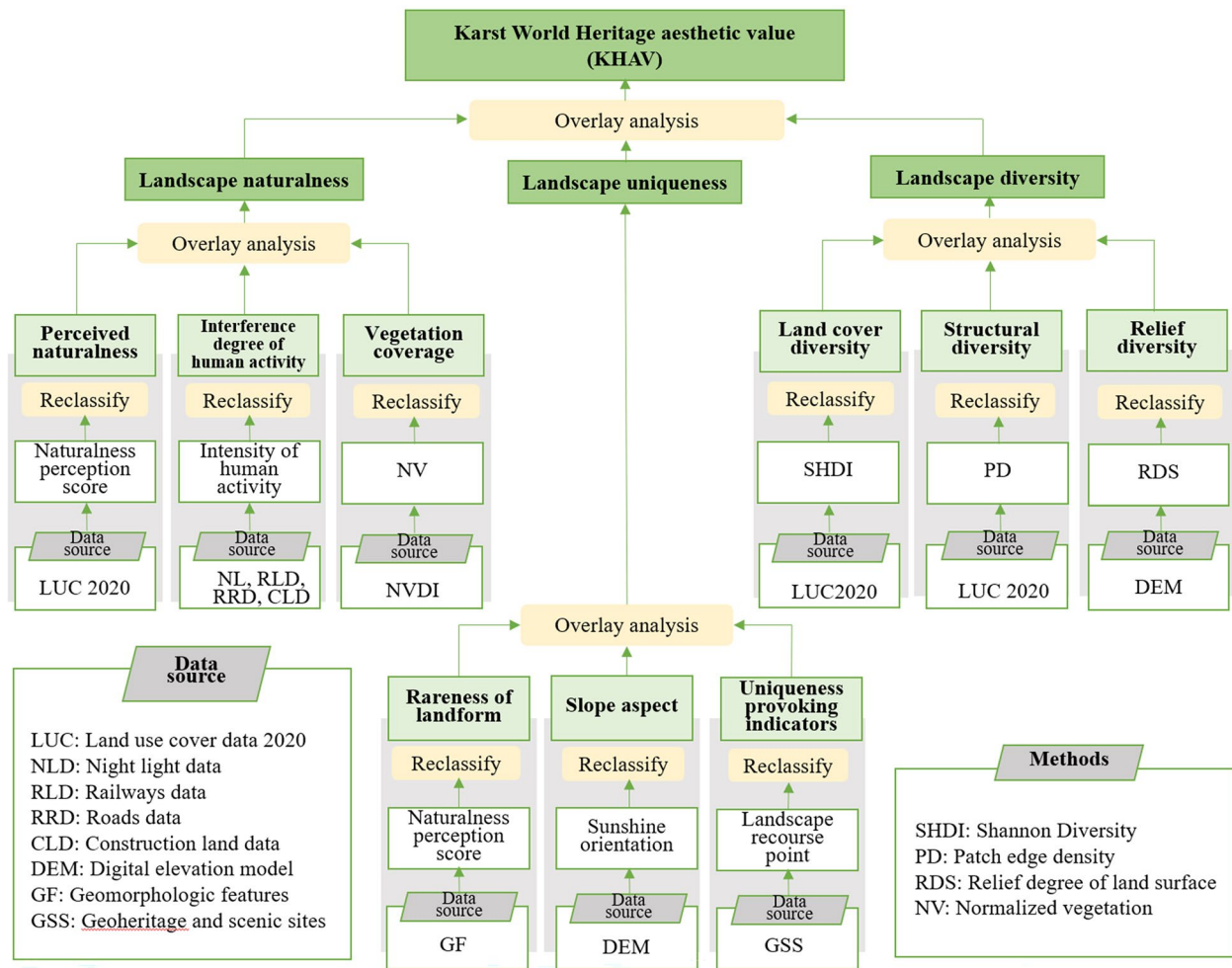


Fig. 2 Framework for aesthetics value mapping and assessment in Huangguoshu scenic area

$$X' = \frac{X - X_{min}}{X_{max} - X_{min}}$$

The normalization formula for the negative index is:

$$X' = \frac{X_{max} - X}{X_{max} - X_{min}}$$

In the formula:

X' is the dimensionless value after normalization, X is the original value, X_{min} is the minimum value of the original value, and X_{max} is the maximum value of the original value.

Step 2 For each index, the indices are weighted and summed to obtain the scores for landscape naturalness, diversity and uniqueness; each dimension is then mapped.

Step 3 The aesthetic value index of natural aesthetic value is obtained by equally weighting and then summing the three dimensions of landscape naturalness, diversity and uniqueness; it is then mapped.

Step 4 Based on the natural breaks (Jenks) method, the esthetic value index of the natural landscape is divided into 5 grades, namely, low, relatively low, medium, relatively high, and high. Its features are then analyzed via spatial visualization.

This research will use the comprehensive index method to comprehensively evaluate the aesthetic value of natural landscapes and calculate the aesthetic value index of natural landscapes:

$$KHAV = \sum_{i=1}^n w_i X'_i$$

In the formula:

$KHAV$ is the natural aesthetic value index of karst heritage, n represents the number of indicators, w_i is the weight value of indicator “ i ”, and X_i' is the normalized value of indicator “ i ”. The greater the $KHAV$ is, the greater the aesthetic value of the natural landscape.

Results

Distribution characteristics of landscape naturalness, diversity and uniqueness

As shown in Fig. 3, the naturalness degree of the total landscape is generally high, and the areas with low, relatively low, medium, relatively high and high value

account for 11.81%, 13.44%, 22.19%, 34% and 18.56%, respectively. The curve of landscape naturalness scores shows a very strong tendency to high values (Fig. 4). The spatial trend gradually increased from north to south (Getuhe Scenic Spot > Huangguoshu Scenic Spot > Tunpu Scenic Spot). The main reason is that the Getuhe Scenic Spot has formed a unique karst forest ecosystem, enabled by the topography of steep rock cliffs, limited accessibility due to inconvenient transportation, and preserved vegetation due to less human-caused damage. The Blind Valley has primitive, dense forests characterized by trees, shrubs, vines and many other plant species, including rare tree species, and wildlife; the ecology, biodiversity

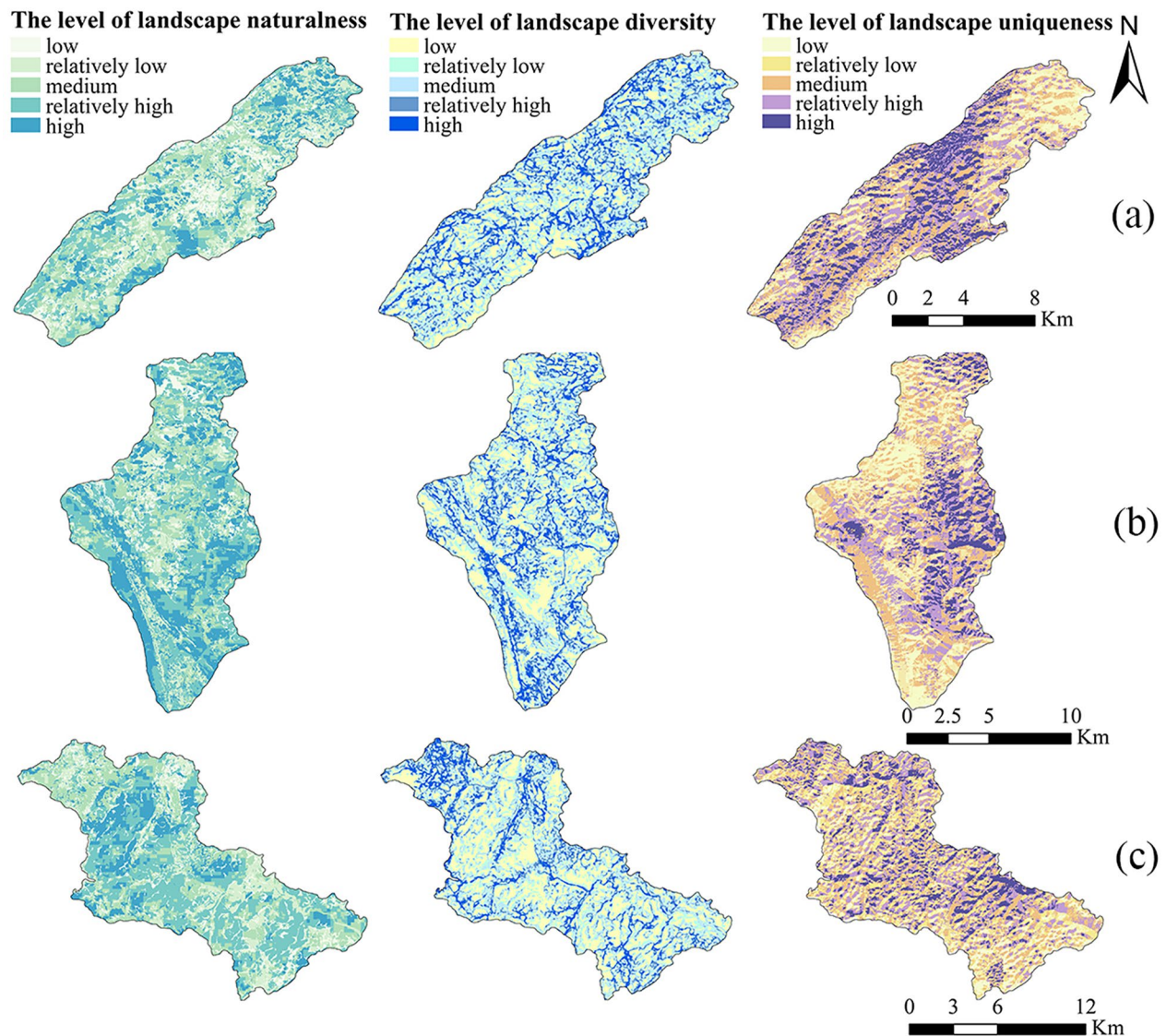


Fig. 3 Evaluation results and spatial distribution of landscape naturalness, diversity, and uniqueness **a** Tunpu Scenic Spot, **b** Huangguoshu Scenic Spot, **c** Getuhe Scenic Spot)

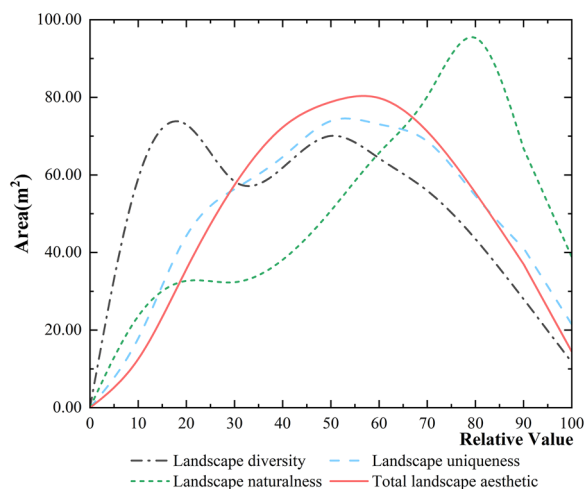


Fig. 4 Area covered per score point of relative

and environment of this area are unique. The large area of water in the Huangguoshu Scenic Spot is obviously perceived as natural; the land type is dominated by natural grassland, shrub and tree woodland; and the zonal evergreen broad-leaved forest and vegetation have developed in an environment high in calcium, drought, and rocky structures, which are defined as “karst vegetation”. The land cover types of the Tunpu Scenic Spot are mainly paddy fields, shrubs and grasslands, with obvious seasonal landscapes and low natural landscapes in autumn and winter. Although the intensity of human activities in the Tunpu Scenic Spot is much greater than that in the Getuhe Scenic Spot, the corresponding occupied space is much less than that of natural areas, so the impact on nature is minimal.

Comparably little area scores very high on landscape diversity (Fig. 4). The areas with low, relatively low, medium, relatively high and high grades accounted for 25.69%, 22.08%, 25.27%, 18.44% and 8.51%, respectively (Fig. 3). Spatially, the grade gradually decreased from north to south (Tunpu Scenic Spot > Huangguoshu Scenic Spot > Getuhe Scenic Spot). There are several potential reasons for this. In the high value area of the Tunpu Scenic Spot, the new source erosion, which results from the downward flow of rivers caused by crustal uplift has not reached the plateau watershed; thus, the landform has developed into the later stage of karst and formed typical cone-shaped fenglin, fenglin-plain, large-scale dissolution basins. A typical karst river valley developed in the high value area of the Huangguoshu Scenic Spot. Due to the frequent transformation between vertical and lateral geomorphic development, the relative elevation difference and topographic relief in this area are large. The significant spatial diversity of the Getuhe Scenic Spot is

due to the dramatic changes in the underlying foundation of the channel basin caused by neotectonic movement, which has formed a horizontal and vertical spatial division with high topographic relief, low structural diversity and landscape diversity.

The trend curves for landscape uniqueness and total aesthetic value are similar (Fig. 4). The area with high values of landscape uniqueness is the largest; the areas with low, relatively low, medium, relatively high and high grades are 14.05%, 22.10%, 27.23%, 23.68% and 12.95%, respectively. As shown in Fig. 3. The Tunpu and Huangguoshu Scenic Spots have the most abundant unique landscapes. On the karst plateau, the Tunpu Scenic Spot has the most fully developed karst areas, which include valleys, basins, and rivers; these areas have preserved the unique geomorphological evolution process. There are multiple combinations of dissolution basins, abundant surface water, and superior farming conditions. New tectonic movement has intermittently lifted the ground, and source erosion has caused the river to retreat, resulting in a “seven-eighteen waterfalls” with obvious cascades, which included vertical, and suspended waterfalls; these inclined waterfalls are typical erosional-split waterfalls. Erosion causes knickpoint type falls, forming fractures, karst caves and underground rivers at different points. In addition, the Getuhe Scenic Spot attained the highest value due to its landform rejuvenation development, which is characterized by complex and mysterious karst caves, large underground river systems and karst blind valleys, multiple geological profiles of paleontological fossils, and complex underground rivers.

Characteristics of aesthetic value distribution at different levels

The natural landscape resources of the total landscape are very rich, and the evaluation results show that the areas of high aesthetic value, that is, the areas of high and relatively high grades, account for 11.20% and 23.93%, respectively. The medium area accounted for 32.4%. The low value areas, that is, the areas with low and relatively low grades, accounted for 11.8% and 24.7%, respectively (Fig. 5). These areas with high values are found in the Huangguoshu Scenic Spot and account for 46.32%, which is significantly greater than the average values; the spatial pattern is characterized by high values in the central region and low values in the northern and southern regions. The high value area and the median value area are mainly concentrated in 7 areas, most of which are within the boundary of the heritage site, while some are distributed in the buffer zone.

The Huangguoshu Scenic Spot (Fig. 6) has the largest proportion of high value areas. This area is called the “Karst Waterfall Museum” because of its large waterfalls

and cascade karst waterfall groups; furthermore, the area contains forest landscapes, canyon ecological landscapes and valley landscapes, which together form a three-dimensional combined landscape with extremely high aesthetic importance. Second, the Tunpu Scenic Spot (Fig. 7), which has flat and open terrain, is a well-developed karst region that features as combination of cone fenglin and large corrosion basins. The land structure of the high value area is dominated by hills and wide valleys, and low mountain clusters are widely distributed in the countryside. The landscape assemblage has a strong sense of hierarchy and is called “a bright pearl in mountains”. Finally, the landscape of the high value area in the Getuhe Scenic Spot (Fig. 8) combines karst canyons and caves and has dense native vegetation; these factors contribute to its prominence in the rankings. It contains almost all the features of karst landforms, such as fenglin, fengcong, gorges, valleys, and depressions, most of which are rarely seen anywhere.

The medium value area is evenly distributed throughout the landscape and is mainly located in the high value area and low value area of each area. Its proportion is the highest in the Getuhe Scenic Spot, accounting for 32.56%. In these areas, the land type is dominated by forest; thus, the perception of its naturalness is high. However, its scores for land type diversity, rarity and structural diversity are low; thus, the area is not very unique. The percentages of medium value areas in the other two areas account are both approximately 26%. Due to its substantial topographic relief, high land cover diversification and wide distribution of landscape uniqueness but low naturalness, the aesthetic value is at a medium level, especially for the Tunpu Scenic Spot.

The distributions of low value areas in each scenic spot vary significantly. The low value area of the Getuhe Scenic Spot accounts for 44.78%, which is much greater than the total average and mainly affected by the dimension index of landscape diversification. The low value areas in the Tunpu Scenic Spot and Huangguoshu Scenic Spot are partly contained. In the Tunpu Scenic Spot, towns with more intense human activities have a lower degree of naturalness in the surrounding areas; these areas have more trunk roads bordered by buildings. Second, the main land types in the low value area are highway land, facility land and bare rock stony land, which have low perceived naturalness scores. Third, the construction of tourist facilities and the high density of tourist activities negatively affect the values of these areas.

Aesthetic value identification and comparative analysis of nominated WH sides

The results show that 38.05% of the seven nominated sites have high natural aesthetic value, which is significantly greater than the average value of the whole landscape, indicating that heritage sites are superior in terms of natural landscape resources (Fig. 9). This study extracted the aesthetic value of nominated NWH sites according to their scope. The natural aesthetic value advantages of the sites, from high to low, are the *Huangguoshu Waterfall*, *Dishuitan Water fall*, *Gaodang Ancient Village*, *Ancient Irrigation System*, *Yunshantun-Benzhai ancient village* and *Tiantaishan Ancient Temple*, and *Getuhe*. The percentages of high value areas corresponding to these places are 64.32%, 52.64%, 45.40%, 43.3%, 43.25%, 35.51% and 24.28%, respectively (Fig. 10).

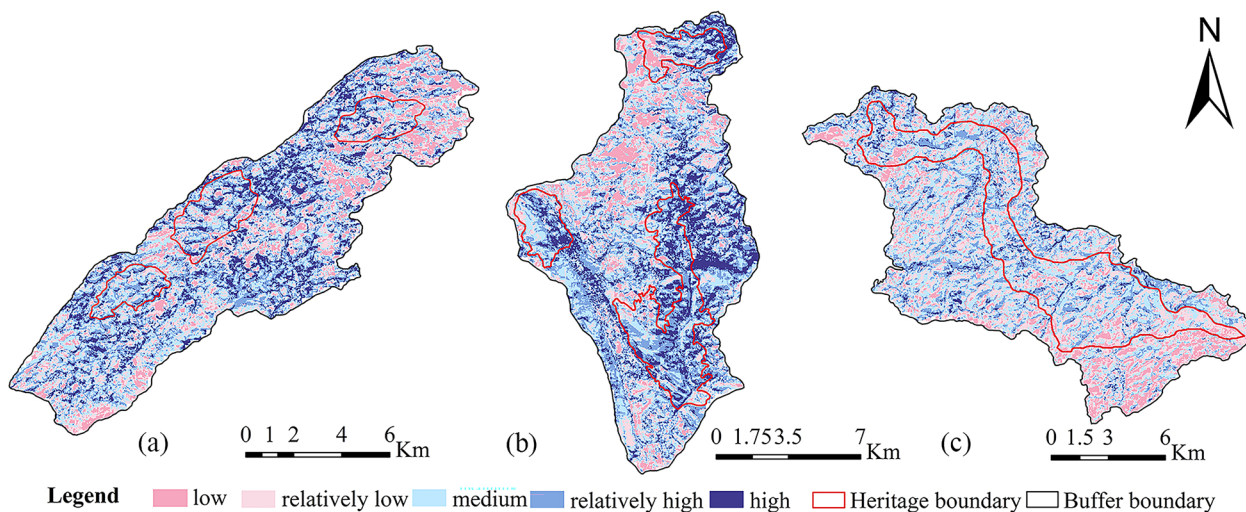


Fig. 5 Evaluation results and spatial distribution of natural aesthetic value in Huangguoshu Scenic Area (a) Tunpu Scenic Spot, (b) Huangguoshu Scenic Spot, (c) Getuhe Scenic Spot



Fig. 6 The aesthetic value in Huangguoshu Scenic Spot (large waterfalls and cascade karst waterfall groups)



Fig. 7 The aesthetic value in Tunpu Scenic Spot (a well-developed karst region that symbolizes the combination of cone fenglin and large corrosion basins)

The scores were ranked, combined with field research, and the landscape characteristics of each landscape group were condensed. In the first group, large waterfalls serve as the core (Fig. 11a). This group includes various forms of and ever-changing cascade waterfall groups and rich landscape types such as stone forests and swallet streams. The Bouyei Nationalities fully utilize these karst mountain resources by exploiting their mountain and river locations for development purposes. They use the surrounding stones to build stonework villages (Fig. 11b) with exceptional national features, cultivate crops on each bank of the rivers and exploit the river water for irrigation. This landscape group forms a scenic cluster characterized by various karst waterfalls, unique karst

landscapes and farming cultures of the Bouyei nationality in the plateau basin.

The second landscape combination is centered on the scenic spots of *Baojiatun Ancient Irrigation System* and other iconic landscapes, including *Yunshantun-Benzhai ancient village* and *Tiantaishan Ancient Temple*, which are characterized by conic fenglin in the plateau basin and plateau basin farming culture. These landscapes merge to form an intact rice-water conservancy farming pastoral scenery; ancient irrigation systems are evident. Moreover, the largest and most complete ancient village is preserved here, and the karst buildings in the village reflect the local people's understanding and practice of natural beauty. The third landscape combination is the

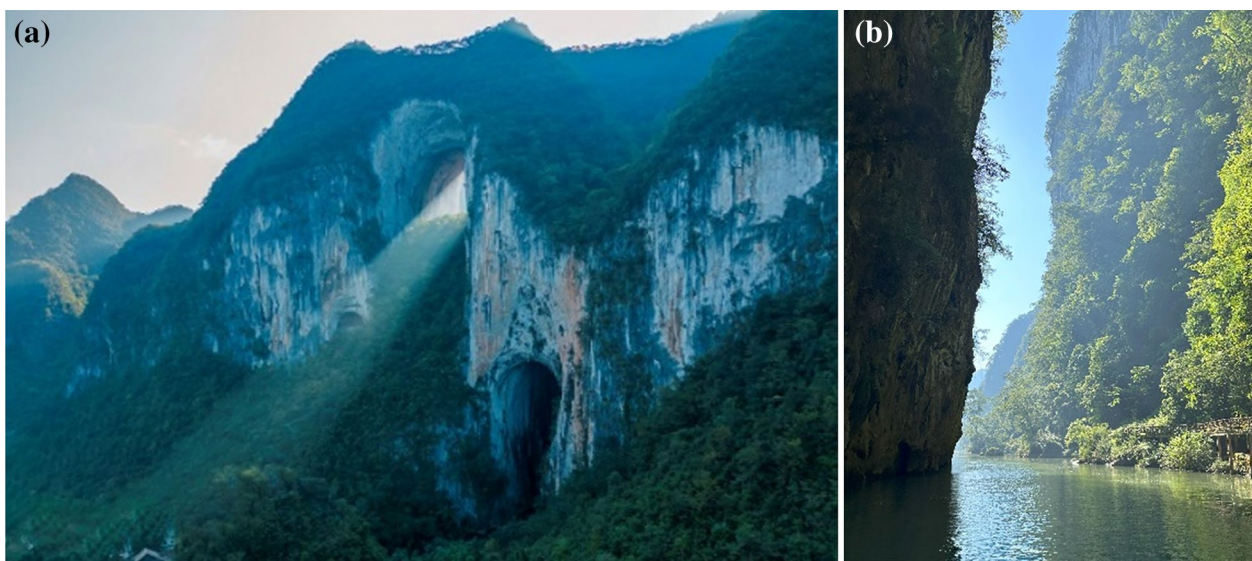


Fig. 8 The aesthetic value in Getuhe Scenic Spot (a. A three-dimensional group of caves; b. The deep canyon)

core area of the Getuhe Scenic Spot. This area is represented by canyons and three-dimensional cave groups; it includes an underground cave that has the largest volume (10 780 000 m³) and deepest shaft (216 m) in the world. This landscape combination integrates canyons and rivers, native vegetation and Miao culture. The above analysis indicated that the evaluation identified the key areas of natural karst beauty in the study area. These nominated NWH sites fully contain unique karst landforms and their corresponding aesthetic landscapes.

Discussion

Through the assessment and mapping process of aesthetic values in this case study of the nominated NWH sites in the Huangguoshu Scenic Area, this research essentially sought a general method for identifying areas with high landscape aesthetic value. The versatility of this approach is reflected by the indicators that were selected based on the literature review. These indicators not only represent the ecological environment of karst landscapes but also represent the aesthetic value generated by public perception in general aesthetic research.

The evaluation results show that the distribution of aesthetic value is basically consistent with the boundary

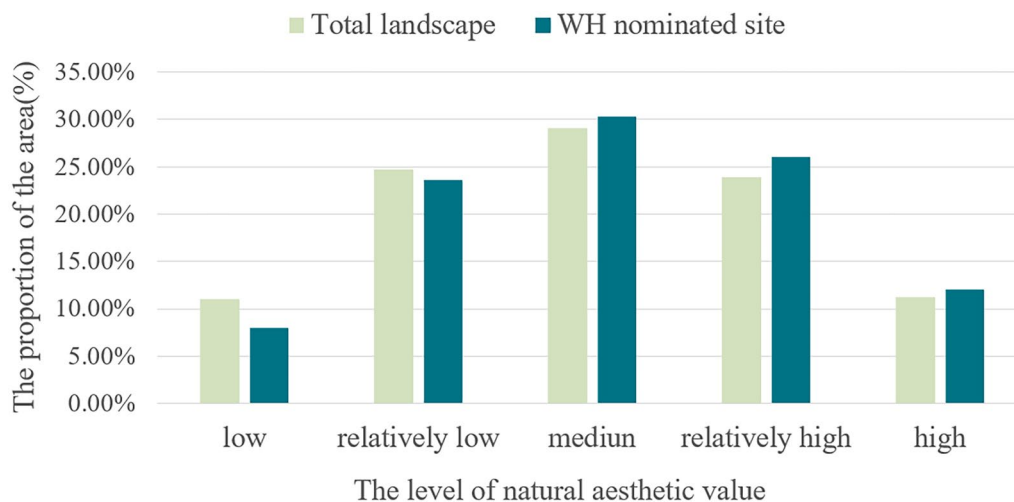


Fig. 9 Comparison of natural aesthetic values of nominated sides and Huangguoshu Scenic Area as a whole

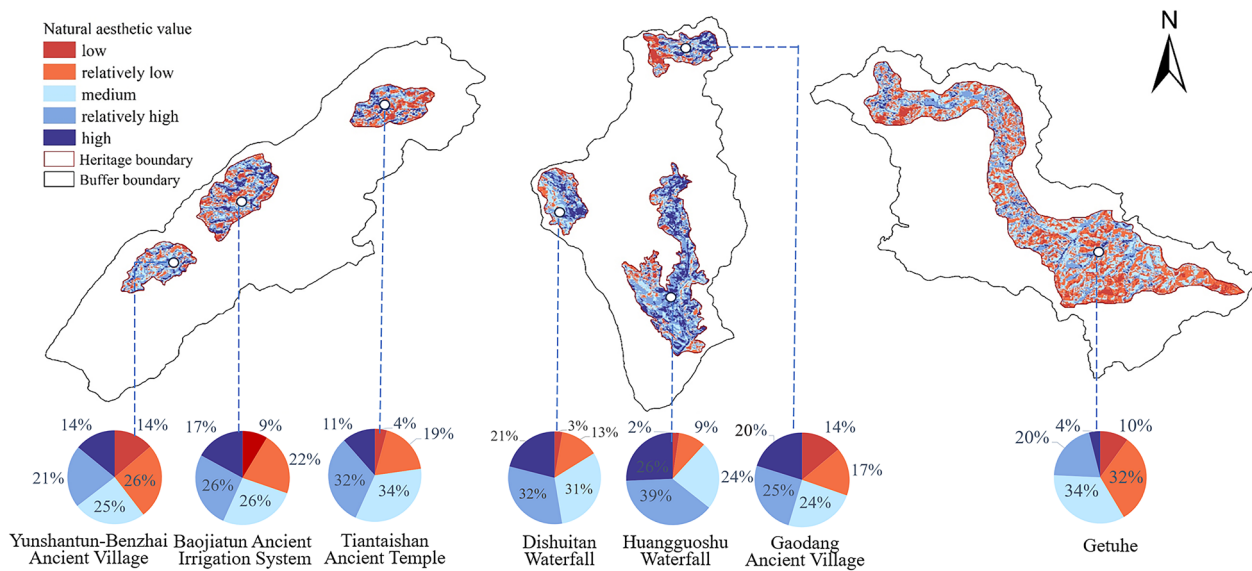


Fig. 10 Evaluation result of natural landscape aesthetic value of nominated sides in total landscape



Fig. 11 The aesthetic value in nominated sides (a. The huangguoshu Waterfall; b. Stonework village)

division of heritage sites, and high scores are mostly distributed in areas with high protection levels; these findings indicate the rationality of the evaluation system for extracting areas with high aesthetic value. Moreover, the results are in line with those of other studies that consider waterfalls, canyons, peaks, and caves to constitute visually attractive landscapes that typically garner much interest and attention, as they are key determinants of natural beauty [19, 44–48]. Furthermore, landscape aesthetic features of natural protected areas are not solely determined by individual landforms or land use elements

but are the result of interactions among various landscape elements. Overall, only the existence of superior landforms and land use at the same time is conducive to shaping high-level landscape features [19, 49]. Finally, the high value landscape combines the quintessential nature of karst, hills and water, caves, fenglin, and historic villages; it unifies sturdiness, peculiarity, precipitousness, and peace. It has the highest level of natural phenomena and aesthetic importance. This finding is also consistent with UNESCO’s description [26].

Compared with this approach, which involves former heritage value identification practices, investigations of the spatial distribution of visual elements are difficult and laborious to undertake, as are investigations of their associated statistics. The availability of data is another reason why this approach could be used universally in the future. In former practices, several methodologies were used to assess aesthetic value by linking social and expert opinions [43], philosophy of aesthetics [37, 50], visual aesthetic quality [51–54], the choice experiment method [19, 55, 56] and the aesthetic preferences of different groups [18, 57, 58]. Despite the numerous existing methods, it is well known that they may not be comparable on an equal basis, thus leading to the disagreements on how to assess natural beauty properly. To see aesthetics in a broader, more comparable form, it is important to follow the idea proposed by Daniel [59] and try to move toward more objective metrics that could be used as a basis for comparability of results between different NWH sites.

By quantifying aesthetic value at NWH sites for the first time, this paper has proven that geographic data representing physical properties can be used for describing natural beauty. On the one hand, the evaluation provides a basis for the demarcation and adjustment of heritage site boundaries, ensures that important high value natural landscape resources can be included in the heritage system, and realizes the comparison of similar heritage sites in different countries and regions. On the other hand, karst heritage sites need to strictly protect the fragile ecological environment and give full play to the economic value of ecotourism to realize the synergy between ecological protection and regional development. The results of the case study can help planners and decision makers organize space scientifically, design ecotourism routes, and layout recreational facilities.

Notably, the results show that there are still many highly rated areas that are not reasonably open to the public. Because natural heritage spaces are traditionally divided into core and buffer zones, policy makers tend to develop tourism facilities in places of high natural landscape value or to implement strict conservation measures in areas of high ecological vulnerability [60]. The demarcation of the nominating site boundaries needs to consider other OUVs nominated together, and some areas of high landscape aesthetic value may be overlooked. The ecological fragility of karst landscapes can be divided into four types of areas according to the aesthetic value of the natural landscape and the strength of ecological vulnerability, and a management direction is proposed. The first is ecological control areas, that is, places with high natural landscape value and ecological vulnerability, where full ecological risk assessments and carefully developed tourism are needed. The second is natural development

areas with high ecological fragility and low landscape value, which are suitable for strict ecological protection. The third is landscape priority areas, which have high landscape value and low ecological vulnerability and are suitable for the future development of natural tourism. The fourth is landscape coordination areas, which have low natural landscape value and ecological vulnerability, no conflict tendency, and are suitable for the construction of accommodations, road transportation and other supporting natural tourism infrastructure. There are several limitations in this study. First, in this study, naturalness, diversity and uniqueness are evaluated, but the connotation of landscape aesthetic value is rich, and not all dimensions, such as sound landscapes and olfactory landscapes, are considered; these dimensions need to be further studied. Second, due to the availability of data and other factors, some indicators are relatively simple and thus not fully representative; furthermore, various types of data with different spatial resolutions can produce errors in the conversion process. Finally, there is a lack of preference analysis for individual landscapes such as caves and stone forests or different landscape combinations. These problems need to be improved upon in subsequent studies.

Conclusions

Existing studies have provided valuable insights into the relationship between the physical features of landscapes and people's subjective aesthetic values but have rarely mapped and assessed the results with measurable indicators. It is crucial to develop an indicator system that is broadly applicable to the aesthetic evaluation of NWH sites. This study constructed an evaluation framework in which the evaluation methods of landscape ecology and aesthetics are integrated, and the key indicators of landscape evaluation are selected from the three dimensions of naturalness, diversity and uniqueness. A case study is conducted in the Huangguoshu Scenic Area, China, to verify the proposed model, which is one of the OUVs of the nominated NWH sites. By calculating and processing FRAGSTATs and ArcGIS with multisource data, the visual results of each metric are obtained.

The results show that the degrees of influence of different dimensions and elements on karst landscape aesthetic value are obviously different. According to the analysis of the difference degree and contribution of each dimension and each index, from high to low are naturalness, uniqueness and diversity. Moreover, in the Huangguoshu Scenic Area, the landscape combines karst, hills and water, caves, fenglin and historic villages, thus unifying sturdiness, peculiarity, precipitation, and peace. This area has the most natural phenomena and high aesthetic

importance. Furthermore, the distribution of aesthetic value is consistent with the boundary of heritage sites, and the areas with high aesthetic value are mostly distributed in areas with high protection levels, which indicates the rationality of the evaluation system. The method and results respond to UNESCO's request for quantitative evaluation for the natural beauty of WH site that can effectively inform planning and decision-making in related scenic areas. Future research will be focused on the value of natural beauty from dimensions such as landscape sound, considering the aesthetic preferences of the public, integrating high-precision data to provide new avenues for research, and, most importantly, refining this approach for more types of natural landscapes according to their aesthetic value and ecological vulnerability.

Abbreviations

DEM	Digital elevation model
WH	World Heritage
NWH	Natural World Heritage
NDVI	Normalized difference vegetation index
OUV	Outstanding universal value
IUCN	International Union for Conservation of Nature
UNESCO	United Nations Educational, Scientific and Cultural Organization
WHC	World Heritage Committee
SHDI	Shannon diversity index
PD	Patch edge density
GIS	Geographic information system

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Author contributions

MZ and KNX developed the concept of this work. MZ wrote the manuscript, KNX reviewed the whole text and made comments and suggestions to improve it. XZ and XXL were involved in collecting data and producing some of the images. All authors read and approved the final manuscript.

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Availability of data and materials

Datasets used and/or analyzed during the current study are available from the corresponding author on reasonable request.

Declarations

Ethics approval and consent participate

Not applicable.

Competing interests

The authors declare no competing interests.

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